Ultra-marathon running

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Abstract: An ultra-marathon can be defined as any running performance lasting for longer than six hours and/or longer than the classical marathon distance of 42.195 km. An ultra-marathon can be held as a single stage race in distance- and time-limited races and as a multi-stage race. The longest ultra-marathons cover several thousands of kilometres and can endure for up to two months. Ultra-marathoners are generally married and well-educated men at the age of 45 years. Female ultra-marathoners account for 20%. Ultra-marathoners differ from marathoners regarding anthropometry and training. Ultra-marathoners complete more running kilometres in training than marathoners do, but they run more slowly during training than marathoners. Previous experience is the most important predictor variable for a successful ultra-marathon performance apart from specific anthropometric characteristics (i.e. low body mass index and low body fat) and training characteristics (i.e. high volume and speed during running training). Women compete slower than men in ultra-marathon running; however, they were able to reduce the sex gap in recent years. The fastest ultra-marathon race times are generally achieved at 35-45 years for both women and men.

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Abstract
An ultra-marathon can be defined as any running performance lasting for longer than six hours and/or longer than the classical marathon distance of 42.195 km. An ultra-marathon can be held as a single stage race in distance- and time-limited races and as a multi-stage race. The longest ultra-marathons cover several thousands of kilometres and can endure for up to two months. Ultra-marathoners are generally married and well-educated men at the age of ~45 years. Female ultra-marathoners account for ~20%. Ultra-marathoners differ from marathoners regarding anthropometry and training. Ultra-marathoners complete more running kilometres in training than marathoners do, but they run more slowly during training than marathoners. Previous experience is the most important predictor variable for a successful ultra-marathon performance apart from specific anthropometric characteristics (*i.e.* low body mass index and low body fat) and training characteristics (*i.e.* high volume and speed during running training). Women compete slower than men in ultra-marathon running; however, they were able to reduce the sex gap in recent years. The fastest ultra-marathon race times are generally achieved at 35-45 years for both women and men.

What is an ultra-marathon?
An ultra-marathon can be defined as any athletic event involving a running distance longer than the traditional marathon length of 42.195 kilometres [1]. Alternatively, an ultra-marathon can also be defined as any running competition lasting longer than six hours, whereas six hours and longer is defined as any ultra-endurance performance. Ultra-marathons can be held as distance-limited races in kilometres or miles and in time-limited races in hours or days [1]. The most often held ultra-marathons in distance-limited races are races in 50 km, 100 km, 50 miles and 100 miles. However, there are also longer running races up to 1000 km and 3100 miles. For the time-limited races, these are held as 6-hour, 12-hour, 24-hour, 48-hour, 72-hour, 6-day, and 10-day races as the most common durations.

Who are ultra-marathoners?
Ultra-marathoners seem to be a very specific kind of athlete. Hoffman and colleagues systematically investigated in recent years socio-demographic characteristics of ultra-marathoners [2,3]. In a survey completed by 489 of 674 runners competing in two of the largest 161-km ultra-marathons held in North America, the included athletes had a mean age of 44.5 years, were generally men (80.2%), were married (70.1%), had a bachelor's (43.6%) or a graduate (37.2%) degree [2]. In the ULTRA-Study, Hoffman and Krishnan [3] interviewed 1,345 current and former ultra-marathoners. The age at the first ultra-marathon race was 36 years and they had 7 years of regular running training before the first ultra-marathon [3]. The age at the first ultra-marathon did not change across the past several decades, but there was evidence of an inverse relationship between the number of years of regular running before the first ultra-marathon and the calendar year of the race [3]. Active ultra-marathoners had a median running training distance of 3,347 km during the previous year, which was minimally related to age but mostly related to their longest ultra-marathon competition of the year [3].

Women in ultra-marathon races
The share of women competing in ultra-marathon races was very low in the first ultra-marathon races [4-6]. In 161-km ultra-marathon races held in the United States of America, participation among women increased from none in the late 1970s to ~20% since 2004 [4]. In two of the most demanding ultra-marathons in the world, women accounted on average for ~21.5% in the 'Badwater' (217 km) and ~10.8% in

the 'Spartathlon' (246 km) [5]. In most ultra-marathon races, the number of female finishers increased across recent years [5,6]. For example, in the 'Swiss Alpine Marathon' (78.5 km) held in the Alps of Switzerland, female participation increased from ~10% in 1998 to ~16% in 2011 [6]. In the 217-km 'Badwater' and the 246-km 'Spartathlon' there was an increase in female participation in 'Badwater' from 18.4% to 19.1% and in 'Spartathlon' from 11.9% to 12.5% in the last decades [5]. The rather low female participation might have different reasons. A potential explanation could be different motivation between women and men in ultra-marathon running. Female ultra-marathoners were task-oriented, internally motivated, health, and financially conscious individuals [7]. Men, however, trend rather to compete in order to beat a concurrent or to win a race.

Where are ultra-marathons held?

Ultra-marathon races are offered all-over the world [1]. There are some well-known races such as the 217-km 'Badwater' held in the United States of America, the 246-km 'Spartathlon held in Greece, and the 230-km 'Marathon des Sables' held in Morocco just to name the most famous races [1]. Some of these races are taking place under extreme conditions such as extraordinary heat such as the 'Marathon des Sables' held in the desert of Morocco [8]. A problem of races held in the heat is the fact that performance will be impaired [9,10], thus, heat acclimation is recommended to help preventing exertional heat illnesses and optimizing performance [11].

Where do ultra-marathoners originate from?

It is well known that East-African athletes such as Kenyans and Ethiopians dominate marathon running all over the world since decades [12,13]. In ultra-marathon running, however, athletes from other regions than East-Africa dominate both participation and performance. For example, in 100-km ultra-marathons competing between 1998 and 2011, most of the finishers originated from Europe, especially from France [14]. The number of finishers from other countries such as Japan, Germany, Italy, Poland and the United States of America increased exponentially [14]. For women, runners from Canada became slower while those from Italy became faster [14]. For men, runners from Belgium, Canada and Japan became slower [14]. Although most 100-km ultra-marathoners originate from European countries, the ten fastest 100-km race times were achieved by Japanese runners for both women and men with ~7:37 h:min and ~6:33 h:min, respectively [14].

In ultra-marathons longer than the 100-km distance, athletes from other countries seemed to dominate both participation and performance [8,15]. Ultra-marathoners competing in the well-known 'Badwater' and 'Spartathlon' originated from different regions [15]. In the 'Badwater' held in the United States of America, most of the finishes were achieved by athletes from the United States of America, Germany and Great Britain. In the 'Spartathlon' held in Greece, however, the highest number of finishes was obtained by athletes originating from Japan, Germany and France. Regarding performance, athletes from other countries were dominating. In the 'Badwater', women from the United States of America were the fastest, followed by women from Canada. For men, the fastest finishes were achieved by competitors from the United States of America, Mexico and Canada. In the 'Spartathlon', the fastest female finishes were obtained by women from Japan, Germany and the United States of America. In men, the fastest finishes were achieved by runners from Greece, Japan and Germany [15].

In the 230-km multi-stage ultra-marathon 'Marathon des Sables' held in the Moroccan desert, local athletes seemed to dominate [8]. In men, Moroccans won nine of ten competitions, and one edition was won by a Jordanian athlete. In women, however, eight races were won by Europeans (*i.e.* France five, Luxembourg two, and Spain one, respectively), and two events were won by Moroccan runners [8]. The abovementioned studies show a variation of nationalities that excel in this sport, however, a small advantage of athletes who race in their country, possibly due to a better acclimatization to the local environmental conditions, was indicated.

How ultra-marathoners differ from marathoners?

Several studies compared recreational ultra-marathoners to recreational marathoners regarding anthropometric [16,17] and training [16-19] characteristics. Ultra-runners start with finishing a marathon before completing the first ultra-marathon. In ultra-marathoners, the number of previously completed marathons is significantly higher than the number of completed marathons in marathoners. However, recreational marathoners have a faster personal best marathon time than ultra-marathoners. Successful ultra-marathoners have about eight years of experience

in ultra-running. Ultra-marathoners complete more running kilometres in training than marathoners do, but they run more slowly during training than marathoners [18,19].

Ultra-marathoners show differences in anthropometric characteristics (*e.g.* skinfolds thickness, limb circumferences) compared to marathoners. Compared to 100-km ultra-marathoners [16], marathoners had a significantly lower calf circumference and a significantly thicker skinfold at pectoral, axilla, and suprailiacal sites. When 24-hour ultra-marathoners were compared to marathoners [17], ultra-marathoners were older, had a lower circumference at both the upper arm and thigh, and a lower skinfold thickness at the pectoral, axillary, and suprailiacal sites than marathoners.

Ultra-marathoners show also differences in training compared to marathoners. Ultra-marathoners rely on a high running volume during training [16,19] whereas marathoners rely on a high running speed during training [16]. When 100-km ultra-marathoners were compared to marathoners [16], marathoners completed fewer hours and fewer kilometres during a training week, but they were running faster during training than ultra-marathoners. When 24-hour ultra-marathoners were compared to marathoners, ultra-marathoners completed more weekly running hours and running kilometres during training, but were running slower than marathoners [17]. Ultra-marathoners have a greater pain tolerance than controls [20] which might enable ultra-runners to endurance longer under different circumstances than others.

Predictor variables for successful ultra-marathon running performance

Several studies tried to find the most important predictor variables for a successful outcome in ultra-marathon running. Among these variables, the most important were age [16,21], anthropometric characteristics such as body fat [16,19], body mass index [22] and limb circumferences [23], training characteristics such as running speed [16,19,21] and training volume [16,19,21] and previous experience [24,25].

Regarding anthropometric characteristics, leg skinfold thickness - which were highly predictive of short-distance track runners [26] - were only predictive in bi-variate analyses, but no in multi-variate analyses, with ultra-marathon running performance [24,27]. In ultra-marathoners, body mass index and body fat seemed to be the most important anthropometric characteristics [22,28]. In 161-km ultra-marathoners, lower values of body mass index were associated with faster race times [22]. Body fat is also an important anthropometric predictor variable. In 161-km ultra-marathoners, faster men had lower percent body fat values than slower men, and finishers had lower percent body fat than non-finishers [28].

When different anthropometric and training characteristics such as skeletal muscle mass, body fat, running kilometres and running speed were compared, body fat and training characteristics were associated with ultra-marathon race times [19]. For 100-km ultra-marathoners, weekly running kilometres and average running speed during training were negatively and the sum of skinfolds were positively related to race time [25]. Apart from anthropometric and training characteristics, age seems also to be an important predictor variable for ultra-marathon performance. In 100-km ultra-marathoners, age, body mass, and percent body fat were positively and weekly running kilometres were negatively related to ultra-marathon race times [16].

Previous experience seems, however, to be the most important predictor variable in ultra-marathon running performance [22,24,29]. Personal best marathon time was a strong predictor in mountain ultra-marathoners [22]. In 24-hour ultra-marathoners, anthropometry and training volume had no major effect on ultra-marathon race time but a fast personal best marathon time showed the only significant association with ultra-marathon race time [24]. To achieve a maximum of kilometres in a 24-hour ultra-marathon, ultra-runners should have a personal best marathon time of ~3:20 h:min and complete a long training run of ~60 km before the start of the ultra-marathon, whereas anthropometric characteristics such as low body fat or low skinfold thicknesses showed no association with ultra-marathon performance [29].

Sex difference in ultra-marathon performance

Women compete slower than men in ultra-marathon running [6,30,31]. Coast *et al.* [31] compared the world best running performances for race distances from 100 m to 200 km. Running speeds were different between women and men where men were ~12.4% faster than women. There was a significant slope to the speed difference across distances where longer distances were associated with greater sex differences [31]. In 24-hour ultra-marathons held between 1977 and 2012, the sex differences were ~5% for all women and men, ~13% for the annual fastest finishers, ~13% for the top ten and ~12% for the top 100 finishers [30]. These findings indicate a variation of sex differences by performance level, *i.e.* the higher the level, the larger the sex differences.

In recent years, women were, however, able to reduce the gap to men [6,30,32]. In 24-hour ultra-marathoners, female and male ultra-marathoners improved performance across years [6,32]. The sex differences decreased for the annual fastest to ~17%, for the annual ten fastest to ~11% and for the annual 100 fastest to ~14% [30]. In 100-mile ultra-marathons, the fastest women and men improved their race time by ~14% between 1998 and 2011 [32]. The relative improvement of women's performance across years might be attributed to the larger number of women participating to sports due to the amelioration of their socio-economic status.

The age of the best ultra-marathon performance

In very recent years, the age of peak ultra-marathon performance and a potential change in the age of peak performance has been intensively investigated [5,6,30,32,33-36]. The best ultra-marathon race performance is achieved at a higher age compared to the best marathon race performance. The fastest female and male marathoners achieved their best race times at the age of ~29.8 and ~28.9 years, respectively [37]. In 100-km ultra-marathoners, the fastest race times were observed between 30 and 49 years for men and from 30 to 54 years for women [34]. In 161-km ultra-marathoners, the fastest times were

achieved by athletes ranked in the 30-39 year age group for men and the 40-49 year age group for women [38].

Women achieved the best ultra-marathon performance at about the same age like men [30,32]. For 100-km ultra-marathoners competing between 1960 and 2012, the age of the fastest female and male finishers remained unchanged at ~35 years [33]. In 24-hour ultra-marathoners, the best performances were achieved at ~40-42 years [35]. In some instances, the age of the fastest finishers increased across years [6], in other instances, it remained unchanged [30,32] or it even decreased [5]. In the annual fastest male 24-hour ultra-marathoners competing between 1994 and 2012, the age of peak running speed increased from 23 to 53 years [30].

There seemed to be a trend that the fastest finishers were older in the very long ultra-marathon distances [30,32]. In 100-mile ultra-marathoners, the mean ages of the annual top ten fastest runners were ~39 years for women and ~37 years for men [32]. In 24-hour ultra-marathoners, the ages of peak running speed were unchanged at ~41 and ~44 years for the annual ten and the annual 100 fastest men, respectively. For women, the ages of the annual fastest, the annual ten fastest and the annual 100 fastest remained unchanged at ~43 years, respectively [30]. In 'Badwater' and 'Spartathlon' as two of the toughest ultra-marathons in the world, the fastest race times were achieved by athletes at the age of ~40-42 years [36].

Master ultra-marathoners

The number of master ultra-marathoners increased and their performance improved in recent years [39,40]. In the 78-km 'Swiss Alpine Marathon', the number of women older than 30 years and men older than 40 years increased and performance improved in women aged 40-44 years [40]. In the 230-km 'Marathon des Sables', the number of finishers of masters runners older than 40 years increased for both sexes and men aged 35 to 44 years improved running speed [39]. A potential explanation for the rather high age of ultra-marathoners could be the finding that the median age at the first ultra-marathon was 36 years in the study of Hoffman and Krishnan [3] when investigating 1,345 current and former ultra-marathoners.

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